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INVESTIGATIONS ON LIGHT AND HEAT, made and published wholly or in part with appropriation from the RUMFORD FUND.

VIII.

ON THE HEAT PRODUCED BY THE RAPID MAGNETIZATION AND DEMAGNETIZATION OF THE MAGNETIC METALS.

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THE fact that iron and steel become heated when rapidly magnetized and demagnetized, has long been known. It is, perhaps, one of the most significant facts in the subject of magnetism; for it is an outward manifestation of the inner work that is done among the molecules when they are endowed and then suddenly deprived of the state which we call magnetism. It gives color to the theory that each particle of iron is given a polarity, and also is twisted or strained in its bed, or caused to vibrate; and brings the subject of the magnetic state of metals into the domain of mechanics, instead of relegating it to the theory of fluids. When we magnetize a bar of steel, the magnet with which we magnetize is not sensibly altered, — it has the same strength as before, — while the piece of steel has been endowed with a new property. How is the doctrine of the conservation of force satisfied? The resulting magnetic state in the piece of steel is not the equivalent of the mechanical motion which the hand gives to the stroking magnet; for it is not necessary to move the magnet. The piece of steel can be left in contact with the poles of the magnetizing magnet. We are forced to conclude that the particles of the steel have been forced into a state of strain, in which the mechanical properties, such as elasticity and viscosity, are involved; and, when we deprive a piece of steel of this mechanical condition, we heat it, just as we can heat a rod of glass or of steel, by stroking it with a cloth covered with resin, and thereby setting it into longitudinal vibration. The rod of glass or steel gives forth a musical note when thus set into longitudinal vibration.

The rod of iron or steel, also, when rapidly magnetized and demagnetized, gives forth a musical note.

Owing to the great kindness of Mr. Joseph Wharton, of Philadelphia, who had provided us with fine specimens of nickel and cobalt bars of his manufacture, and to the courtesy of the officers of the United States Torpedo Station at Newport in allowing us the use of a Wilde's alternating dynamo-electric engine, we were enabled to make the following experiments upon the rapid magnetization and demagnetization of the magnetic metals, iron, steel, cobalt, and nickel.

To measure the strength of the current produced by the dynamo-electric machine, we made use of an electro-dynamometer similar to that described in Maxwell's "Electricity" which was constructed on the Helmholtz Gaugain principle both in the fixed and movable coils, and had a resistance of 58.93 of an ohm. The movable coil was suspended from a graduated circle, which read, by means of verniers, to one minute. This circle, however, was only used as a check upon the readings given by a mirror placed upon the movable coils. The telescope and scale were placed seven feet from the mirror. The electro-dynamometer was provided with a shunt of one tenth of an ohm, made out of broad ribbons of German silver, the resistance of which did not alter perceptibly during our experiments. Three coarse wire coils of resistances

A	B	C
.362	316	.323

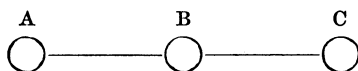
were provided with glass tubes filled with water, which were carefully placed so as not to conduct heat from the coils surrounding them. The bars of cobalt, nickel, iron, and steel, were all of the same size, viz. :—

length, 15.15 cm.

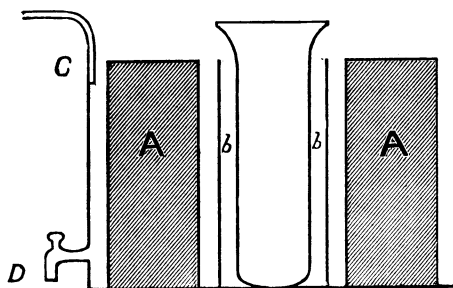
diameter, 1.25 cm.

Three thermometers, made by Geissler of Bonn, were used, and their readings were subsequently carefully compared with those of a standard Centigrade thermometer, the graduation of which had a probable error of one hundredth of a degree. For this thermometer we were indebted to Professor H. B. Hill, Harvard University. The coils and the thermometers were used in alternation; and the experiments were combined so as to give as many experimental equations as were possible in the short time to which the experiments were necessarily limited on account of the rapid heating of the circuit, and also of the rapid rise of temperature of the water in which the magnetic metals were immersed.

The order of the experiment was as follows : —



In A, B, and C, were placed glass tubes which contained equal volumes of water. Each tube was provided with a thermometer, which was designated by a number engraved upon it. In A, no metals were placed; and the thermometer in this tube consequently gave the change of temperature which resulted from the heating of the coils by the passage of the electric current. Subsequently, we devised an arrangement shown in the accompanying figure. Fig. 1 is a section. The vessel was made of tin with a cylindrical hole in which was placed the



glass tube; and the space *b*, Fig. 1, around it, was packed with infusorial earth. A current of water entered at C, Fig. 1, and passed out at D. A represents a section of the coil. This arrangement, however, was not used; for we found that, by limiting the experiments to a short time, no appreciable error resulted from the heating of the coils themselves. Our object was only to observe the rise of temperature in a given time, that of one minute. In the following table, the temperature readings in Centigrade degrees are given from the tubes placed in the coils A, B, and C. At the head of the columns B and C are placed the names of the metals employed. The temperatures were taken before and after the experiments.

(1) Water. A			Cobalt. B			Iron. C		
Before.	After.	Diff.	Before.	After.	Diff.	Before.	After.	Diff.
16.33	16.33	0	16.61	22.97	6.36	16.56	23.40	6.84

Cobalt.

C°			C°		
Before.	After.	Difference.	Before.	After.	Difference.
16.33	18.51	2.18	18.51	26.35	7.84

Resistance of circuit, 2.64 ohms.

Current in Vebers, before metal was placed in coil . . .	23.97
„ after „ „ . . .	21.715
Difference	<u>2.255</u>

Mechanical equivalent = 1363.1 metre grammes.

No. of reversals of magnetization per minute 5880

Steel.

C°			C°			C°		
Before.	After.	Diff.	Before.	After.	Diff.	Before.	After.	Diff.
16.14	16.80	.66	16.86	21.60	4.74	17.04	28.02	10.98

Resistance of circuit, 2.64 ohms.

Current in Vebers, before metals were placed in coils	. .	24.355
„ after „ „	. .	20.208
Difference		4.147

Mechanical equivalent = 4528.3 metre grammes.

No. of reversals of magnetization per minute 5784

Practically, the same result was given when a bar of steel was substituted for the iron.

Nickel.

C°		Difference.	C°		Difference.
Before.	After.		Before.	After.	
16.80	19.22	2.42	16.56	21.79	5.23

Resistance of circuit, 2.64 ohms.

Current in Vebers, before metals were placed in coils . .	24.169
„ after „ „ . .	22.848
Difference	8.321

Mechanical equivalent = 455.2 metre grammes.

No. of reversals of magnetization per minute 5808

The following table exhibits the work done, expressed in metre grammes, in magnetizing and demagnetizing equal volumes of the metals in one minute:—

Metals.	Metre grammes.	No. of reversals in one minute.
Iron	2112.	5,700
Cobalt	1363.1	5,880
Nickel	455.2	5,808
Cobalt and Iron . . .	5144.2	5,844
Cobalt and Nickel . . .	2758.5	5,904
Nickel and Steel . . .	4528.3	5,784

The electrical measurements contained in the above tables consisted in deducing the current in Vebers from the deflections of the movable coil of the electro-dynamometer, which was placed in the magnetic meridian. The expression for the current is

$$C = \sqrt{\frac{F}{Gg} \tan \theta}$$

Where F is directive force of bifilar suspension.

G and g constants of fixed and movable coils.

In the instrument used, the value of $\frac{F}{Gg}$ was 10.4

The resistance of the circuit was measured as accurately as possible. The variations in the current were undoubtedly due to the heating of the machine itself. It was to be regretted that we were not enabled to measure the resistance of the circuit more accurately. This was impossible, under the conditions of the experiments. The mechanical equivalent of the current consumed in heating the metals was deduced from the expression

$$W = \text{work} = C^2 R t.$$

The current 1 Veber in a conductor of resistance one ohm = $1.000000 \times 10^6 \frac{\text{mm}^2 \cdot \text{mgr.}}{\text{sec}^2}$. Which reduced to the unit of work is equal to $\frac{1.000000 \times 10^6}{9806 \times 10^6} = 102. \text{ metre grammes.}$

The analyses of the cobalt and nickel were as follows:—

- Nickel 1. 3.1328 grammes gave 0.0115 gramme Fe_2O_3 .
 0.0115 gramme $\text{Fe}_2\text{O}_3 = .00805 \text{ Fe} = 0.256 \%$.
- Nickel 2. 4.3002 grammes gave 0.0178 gramme Fe_2O_3 .
 0.0178 gramme $\text{Fe}_2\text{O}_3 = 0.01246 \text{ Fe} = 0.289 \%$.
- Cobalt 1. 4.2264 grammes gave 0.0492 gramme Fe_2O_3 .
 0.0492 gramme $\text{Fe}_2\text{O}_3 = 0.03444 \text{ gramme Fe}_2 = 0.814 \%$.
- Cobalt 2. 4.5606 grammes gave 0.0358 gramme Fe_2O_3 .
 0.0358 gramme $\text{Fe}_2\text{O}_3 = 0.02506 \text{ gramme Fe} = 0.55 \%$.
- Cobalt 3. 3.3940 grammes gave 0.1091 gramme Ni O.
 0.1091 gramme Ni O = 0.08571 gramme Ni = 2.52 %.

The weight of bar of cobalt was 163 grammes approximate.

„ „ nickel „ 159 grammes approximate.

The bars of nickel, cobalt, iron, and steel, all emitted loud musical notes while in the process of being magnetized and demagnetized, the note emitted by the iron being the loudest. These notes could easily be heard two hundred feet away from the bars.

Among the papers published on the magnetic metals is one by Professor Barrett of the Royal College of Science, Dublin, which is entitled “The Molecular Changes that accompany the Magnetization of Iron, Nickel, and Cobalt.” After giving a *résumé* of what has been written on this subject, the author remarks: “Nickel is invariably ranked above cobalt in the scale of magnetic metals, Faraday and others placing it next to soft iron. But the bar of nickel I have used, when submitted to the same magnetizing current as the cobalt bar, exhibits far less portative force than the cobalt. It is remarkable that the iron impurity contained in the cobalt is able to produce so powerful an influence. The nickel, like other specimens I have met with, has a very slight retentive power when magnetized; whereas, the cobalt has a high degree of coercive force.”

It appears from our result that it is not the iron in the cobalt which produces the high amount of molecular heating noticed by us; for the chemical analyses showed an amount of iron which would be inappreciable in the electrodynamic experiments.

The following table, for which we are indebted to a paper by Professor W. F. Barrett, published in the London “Philosophical Magazine,” 1873, Vol. XLVI. page 478, exhibits the relationship of the magnetic metals:—

Sub-stance.	Den- sity. Wa- ter = 1.	Atomic Weight H = 1.	Specific Heat. Water = 1.	Atomic Heat.	Dilatation		Conductibility		Tenacity and Melting Point.
					by Heat.	by Strain.	for heat. Silver. = 1.	for sound. Air = 1.	
Iron. .	7.8	56.0	0.1138	6.38	.0926	.0387	.168	15.3	Very high.
Nickel	8.3	58.5	0.1091	6.33	.0899	.0394	.131	14.9	"
Cobalt	8.5	58.5	0.1070	6.26	.0981	.0436	.172	14.2	"

Our results show that in regard to molecular heating, so to speak, by magnetizing and demagnetizing, cobalt stands very close to iron, while nickel is far removed from it.

RECAPITULATION.

1. It appears from the preceding experiment that the rapid magnetization and demagnetization of iron, steel, cobalt, nickel, is accompanied by a marked rise in temperature.
2. Under the same conditions, this rise in temperature is greatest for iron and least for nickel.
3. The rise in temperature of cobalt in some cases may be as much as that of an equal volume of iron.
4. The rise in temperature of the magnetic metals submitted to this process is accompanied by a marked increase of work done by the electrical circuit, which can be readily measured by an electrodynamicometer.
5. The magnetic metals submitted to the above process severally emit loud musical notes, which rank in the following order: iron, cobalt, and nickel.